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Development and Use of Satellite Telemetry to Estimate Post-Hooking Mortality of Marine Turtles in the Pelagic Longline Fisheries

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INTRODUCTION

This document represents the final report for PO Number 40JJNF800147, which had a beginning date of 28 May 1998 and an ending date of 30 March 1999. The analyses in this report are preliminary because transmitters are still functioning and data collection is not complete. Conclusions may change as additional data are collected and analyzed.

Background

It is now well recognized that incidental capture in longline fisheries is a significant threat to sea turtle populations in both the Atlantic and Pacific Oceans (Balazs and Pooley, 1994; Balazs et al., 1995; Williams et al., 1996; Bolten et al., 1996). Recovery of U.S. loggerhead sea turtle (*Caretta caretta*) populations is threatened by takes in the longline fishery in the eastern Atlantic. Sea turtle recovery in the Pacific is threatened by longline fisheries there, in which the U.S./Hawaii based fishery is a small component. However, the U.S. can provide leadership for both Atlantic and Pacific fisheries by estimating loggerhead mortality from these fisheries and working with the industry to develop fishing methods that reduce sea turtle bycatch.

Molecular markers based on mtDNA sequences were recently used to estimate that 90% of the juvenile loggerhead sea turtles in pelagic habitats of the eastern Atlantic (Azores and Madeira) are derived from nesting populations in the southeast U.S. (Bolten et al., 1998). This eastern Atlantic loggerhead population has a range of carapace lengths from 8-65 cm (mean carapace length of 35 cm) Bolten et al., 1993; Bolten, Bjorndal, and Martins, unpub. data). Turtles in this pelagic population are caught as bycatch in the swordfish (*Xiphias gladius*) longline fishery in the Azores, and the largest size classes of loggerheads present in the eastern Atlantic (42-65 cm) are impacted by this fishery (Bolten et al., 1994). Increased mortality in this size class of sub-adults has a major demographic effect (Crouse et al., 1987).

Behavioral studies, using satellite telemetry, on loggerheads caught on longlines will be used to estimate mortality from hooking. Preliminary studies conducted in 1994 and 1995 have shown the success of using satellite transmitters on juvenile, pelagic loggerheads (Bolten et al., 1996) and suggest that satellite telemetry may be the most cost-effective method to determine mortality.

The focus of a workshop held in Hawaii in November 1993 and sponsored by the National Marine Fisheries Service was to develop a research plan to assess the impacts of hooking from longline fisheries (Balazs and Pooley, 1994). The use of biotelemetry to study the behavior and survivorship of hooked sea turtles was identified as a major research priority.

This project was conducted in the eastern Atlantic in the waters around the Azores, using the pelagic-stage loggerhead population as a model. This is an excellent population to use for this study because the population has been well studied (Bolten et al., 1993; 1998); the impact of longline fisheries on this population has been identified (Bolten et al., 1994); and the reliability of catching turtles has been demonstrated from several years of field work. Another advantage of working with this population is that genetic analyses have shown that the pelagic-stage loggerheads in the eastern Atlantic are part of the US nesting population (Bolten et al., 1998).

Objectives:

(1) Conduct a study to assess the behavior and movement patterns of pelagic-stage loggerheads caught in a longline fishery.

(2) Determine the feasibility of using satellite telemetry to evaluate survivorship of released turtles caught in a longline fishery.

METHODS

Eight pelagic juvenile loggerheads were instrumented with Wildlife Computers (Redmond, Washington) satellite-linked Time-Depth Recorders (SDR-T10, model with special rectangular batteries) during fall 1998 (Table 1). The first five of these turtles were captured using dipnets, and the next three were captured using commercial pelagic longline fishing gear. The three turtles captured by commercial longline fisheries were hooked in the mouth. No turtles hooked in the esophagus were available to instrument with transmitters during the field season.

The transmitters were attached to the carapaces of the turtles using a silicone elastomer base, fiberglass strips, and polyester resin as described by Balazs et al. (1996). Turtles were typically released within 2-4 days of capture.

All of the transmitters were programmed using Wildlife Computers software version 3.14k. Each transmitter was programmed according to identical parameters in order to facilitate comparisons (Table 2). The data were received via the ARGOS satellite and data distribution system, and processed using SATPAK software (Wildlife Computers) and the IDL programming language (Research Systems, Boulder, Colorado).

The position with the best location code from each turtle on each transmission day was used to map the movements of individual turtles. The tracks were also layered with a bathymetry image using Surfer software (Golden Software, Golden, Colorado) to determine whether movements show any gross correlations with bathymetry.

In addition to location information, transmitters also collected information on diving behavior. Turtles had to descend at least 2 meters for a dive event to register. This precludes having wash-overs counted as dives. Dive-profile data are received as six-hour composite histograms of the maximum depth attained on each dive, the duration of each dive, dive counts (derived from the previous two histograms), and proportional time at depth. The histogram periods were designated as follows (local time):

Period 0: 2100-0300
Period 1: 0300-0900
Period 2: 0900-1500
Period 3: 1500-2100

We analyzed the dive data to determine whether mean maximum dive depth or dive duration correlates with body mass or carapace length. Using the data from the three unhooked turtles with the longest and most complete transmission records, we determined whether dive behavior has seasonal or diurnal patterns. Using the data from all turtles for a limited time frame during which all of the transmitters were active (January and February 1999), we determined whether dive behavior differs between hooked and unhooked turtles. We compared the mean maximum dive depth, mean dive duration, and mean dive count between hooked and unhooked turtles, on a histogram-period-by-histogram-period basis.

RESULTS

As of 28 February 1999, all of the transmitters continue to function, although transmitter 22531 has transmitted data only sporadically since November 1998, and with insufficient frequency to obtain any location fixes. Battery voltage was still reasonably high (4.8-5.8 V) for all turtles, and transmitter clock drift (+ 0.7 to + 2.0 min) was not sufficient to affect data collection or alter transmission success.

The movements of all of the turtles (except 22531) are shown in Figure 1(a). The tracks of the individual turtles (except 22531) are shown in Figure 1(b–h). The movements of all turtles (except 22531) with respect to bathymetry are shown in Figure 2. We have not yet quantitatively analyzed whether movements or behavior correlate with bathymetry; statistical analyses will be conducted at the end of data collection when transmitters no longer are functioning.

Mean maximum dive depth was not related to mass (kg, least squares linear regression, $R^2 = 0.01$) or length (SCLn-t, $R^2 = 0.00$). Mean dive duration was also not related to mass (kg, $R^2 = 0.03$) or length (SCLn-t, $R^2 = 0.00$). The mean number of dives per six-hour period was also not related to mass (kg, $R^2 = 0.05$) or length (SCLn-t, $R^2 = 0.01$).

Visual inspection of the change in mean maximum dive depth with time does not suggest a seasonal effect (over the months observed) on dive behavior (Figure 3: a-c). A diurnal pattern in dive behavior is evident for turtles 23660 and 23658, with the deepest dives occurring during periods 2-3 (0900–2100). Turtle 23662 does not demonstrate an equally strong diurnal pattern, but this may be related to the fact that 23662 appears to be swimming much more actively (and directionally) than the other turtles (see Figure 1a).

Since there is an apparent diurnal pattern to dive behavior, dive statistics for each turtle were calculated on a period-by-period basis (Tables 3-6). Mean dive count during period 2 (0900-1500) differed between hooked and unhooked turtles during January-February 1999 (2-sample T-test, $T_{\alpha,5} = -3.39$, $p = 0.020$, Table 5). Mean dive count was not significantly different between hooked and unhooked turtles during periods 0, 1, or 3. Mean maximum dive depth and mean dive duration did not differ significantly between hooked and unhooked turtles during any period.

Based on dive histogram data, the maximum dive duration was between 180 and 240 minutes. Four dives fell within this range. Turtle 23657 made 3 of these dives in mid-December, and turtle 23661 made 1 dive of that duration in early February.

Based on the 1-meter resolution maximum depth information obtained from the status messages, the deepest dive was 232 m. This dive was made by turtle 23662 in mid-November.

CONCLUSIONS

- Dive behavior appears to have a diurnal component, with deeper dives occurring during histogram periods 2 and 3 (0900–2100). Turtle 23662 does not show this pattern; however, turtle 23662 is moving further and straighter than either 23660 or 23658 (Figs. 1 and 2) and may be showing a "migratory" dive pattern rather than a "residency" dive pattern.
- Turtles that were caught on longline fishing gear had significantly lower dive counts than turtles caught with dipnets in January and February during period 2 (0900–1500), the period of most intense diving activity.
- Dive duration and dive depth did not show a relationship with body size. However, the range of body sizes used for this study (8.6–30.7 kg) may not have been great enough to allow for this relationship to be detected with the dive histogram data collected by the SLTDR's. Alternatively, differences in dive capacity may exist, but turtles may not regularly dive to capacity, in either depth or duration.
- Dive behavior does not show an apparent seasonal effect.
- All of the comparisons between hooked and unhooked loggerheads must be interpreted with caution. As stated previously, transmitters are still functioning and conclusive analyses cannot be conducted until all data have been collected. Also, the hooked turtles had only been hooked in the mouth, not in the esophagus.

RECOMMENDATIONS

- Satellite telemetry shows excellent promise for the evaluation of the behavior of post-hooked sea turtles from a longline fishery. Additional turtles must be instrumented to increase the sample size to establish both norms of behavior and the effects of hooking.

- Analyses would be enhanced by the collection of dive profiles from an entire year to document seasonal changes in dive behavior. For the current group of turtles, battery life is the limiting factor on the functional life of the transmitter. To extend the battery life and extend the period of data collection, the satellite transmission duty cycle needs to be changed from the current 1-day-on/1-day-off pattern to a less frequent cycle of transmission, e.g., 1-day-on/5-days-off.

- We strongly recommend the continued use of satellite transmitters that provide dive profiles to assess behavioral differences between normal and hooked turtles. Location-only transmitters will not provide sufficient data to allow for analyses of behavioral changes following hooking.

- The interpretation of both movements and dive behavior can be greatly enhanced by integrating this information with environmental data derived from remote-sensing imagery and other oceanographic data sources.

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Table 1.--Juvenile loggerhead turtles (*Caretta caretta*) instrumented with satellite transmitters in the Azores Islands--Fall, 1998.

Transmitter Number	Hooked? Where?	Tag-RF	SCLn-n (cm)	CCL (cm)	SCW (cm)	PL (cm)	Mass (kg)	Date of Release	Release Latitude (N)	Release Longitude (W)
23662	no	A3860	40.8	45.2	36.3	34.0	11.0	9/15/98	38.69	28.66
23660	no	A3862	42.2	46.4	36.5	35.3	12.1	9/17/98	38.17	29.00
22531	no	A3864	37.0	40.5	32.3	31.3	8.6	9/25/98	38.23	28.97
23658	no	A7284	42.0	47.3	38.4	34.8	12.8	10/7/98	38.67	28.63
23661	no	A7286	36.4	39.8	32.2	29.6	7.9	10/12/98	38.52	28.96
23657	mouth	A7288	61.1	65.4	50.2	46.7	30.7	10/28/98	38.29	28.84
22530	mouth	A6173	47.4	51.8	41.2	38.9	15.0	11/11/98	38.23	26.61
23659	mouth	A7291	43.8	47.3	38.3	36.6	12.5	12/5/98	38.51	28.88

Table 2. Satellite transmitter programming configuration.

Quarter-Watt, Microprocessor-controlled Satellite-linked Time-Depth Recorder. Unit measures depth from 0 to 245 meters with a resolution of 1 meters **Software version 3.14k. Unit number:** x **ARGOS geolocation id** $= y$ Unit identifier = . Unit started at 08:42:05 on 14/09/98
Time (GMT) is 08:55:14.51. Date (GMT) is 14 September 1998 Shallowest depth to be considered a "dive" = 2 meters Deepest depth for accumulating surface-timelines (0=dry only) = 1 meters SLTDR uses 1-sec / ¬-sec wakeups when shallower than 20 / 5 meters Local time [0-23 hours] corresponding to 00h UT (GMT): 22 Transmission intervals (at-sea / on-land) = 00:45.50 / 01:30.50 SLTDR will use on-land interval after 10 consecutive dry transmissions SLTDR will not suspend transmissions during extended "Haul-outs". Transmissions will be duty cycled with 1 day on and 1 day off Daily allowance (1-message transmissions; unused xmits accumulate) = 500 STATUS will be transmitted every 20 messages. Blocks of Time-Lines will be transmitted every 48 messages. Hours when SLTDR transmits: 04,07-09,19-22, Upper limits of maximum-depth histogram bins are: 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 100, 150, ì meters Upper limits of dive-duration histogram bins are: 2, 5, 10, 20, 30, 45, 60, 75, 90, 105, 120, 180, 240, ì minutes Upper limits of time-at-depth histogram bins are: 1, 3, 5, 10, 15, 25, 35, 50, 60, 75, 100, 125, 150, ì meters Type D to archive depth readings, H to archive histograms: h

Table 3.--Mean (± 1 standard deviation) dive depths, dive durations, and dive counts during period 0 (2100-0300 local time) for all turtles, between 1-1-99 to 2-28-99.

Turtle Number	**Mean Dive Depth ± SD (meters)**	**n**	**Mean Dive Duration ± SD (minutes)**	**n**	**Mean Dive Count ± SD (# per 6 hr period)**	**n**
23662	8.2 ± 15.8	143	22.1 ± 32.1	123	7.5 ± 11.3	19
23660	4.3 ± 7.8	530	8.4 ± 15.0	537	17.7 ± 19.0	30
22531	--	0	--	0	--	0
23658	4.6 ± 10.4	283	9.3 ± 17.9	340	9.8 ± 15.6	29
23661	5.7 ± 12.4	280	17.2 ± 26.4	232	9.7 ± 11.8	29
23657*	4.2 ± 8.2	482	5.6 ± 12.0	505	14.6 ± 28.0	33
22530*	5.8 ± 12.4	221	16.4 ± 22.9	257	12.3 ± 11.4	18
23659*	6.5 ± 11.4	287	16.4 ± 24.5	282	10.3 ± 10.0	28

*Turtles captured with longline fishing gear.

Table 4.--Mean (± 1 standard deviation) dive depths, dive durations, and dive counts during period 1 (0300-0900 local time) for all turtles, between 1-1-99 to 2-28-99.

Turtle Number	Mean Dive Depth ± SD (meters)	n	Mean Dive Duration ± SD (minutes)	n	Mean Dive Count ± SD (# per 6 hr period)	n
23662	5.4 ± 6.7	775	8.1 ± 17.1	282	26.7 ± 93.8	29
23660	4.1 ± 6.0	1136	6.2 ± 11.4	1140	31.6 ± 33.6	36
22531	20.6 ± 54.2	10	13.8 ± 35.3	32	5.0 ± 7.1	2
23658	4.1 ± 6.2	825	5.7 ± 9.7	981	21.2 ± 19.6	39
23661	5.1 ± 10.6	632	6.3 ± 12.1	845	19.8 ± 17.3	32
23657*	4.3 ± 5.7	1129	4.8 ± 7.8	1166	22.6 ± 17.4	50
22530*	8.8 ± 12.2	320	16.4 ± 21.6	358	11.0 ± 8.8	29
23659*	6.4 ± 9.3	462	15.9 ± 21.8	391	12.2 ± 8.5	38

*Turtles captured with longline fishing gear.

Table 5.--Mean (± 1 standard deviation) dive depths, dive durations, and dive counts during period 2 (0900-1500 local time) for all turtles, between 1-1-99 to 2-28-99. Mean dive count differed between hooked and unhooked turtles (2-sample T-test, $T_{\alpha,5} = -3.39$, $p = 0.020$).

Turtle Number	Mean Dive Depth ± SD (meters)	n	Mean Dive Duration ± SD (minutes)	n	Mean Dive Count ± SD (# per 6 hr period)	n
23662	5.2 ± 6.5	1016	5.4 ± 9.7	443	36.3 ± 95.2	28
23660	4.8 ± 17.08	874	5.9 ± 10.9	995	25.7 ± 21.2	34
22531	5.4 ± 17.1	101	7.9 ± 21.6	64	--	0
23658	4.7 ± 7.2	1851	5.3 ± 8.4	1726	44.1 ± 42.5	42
23661	5.5 ± 8.2	883	7.8 ± 13.6	841	22.6 ± 21.1	39
23657*	6.6 ± 10.0	1743	5.8 ± 7.8	1657	34.2 ± 30.6	51
22530*	13.9 ± 17.0	346	18.2 ± 19.7	322	10.5 ± 10.4	33
23659*	8.0 ± 12.8	315	10.3 ± 16.0	300	8.1 ± 10.9	39

*Turtles captured with longline fishing gear.

Table 6.--Mean (± 1 standard deviation) dive depths, dive durations, and dive counts during period 3 (1500-2100 local time) for all turtles, between 1-1-99 to 2-28-99.

Turtle Number	Mean Dive Depth ± SD (meters)	n	Mean Dive Duration ± SD (minutes)	n	Mean Dive Count ± SD (# per 6 hr period)	n
23662	6.1 ± 11.0	462	7.8 ± 12.9	413	24.3 ± 17.6	19
23660	4.3 ± 7.4	707	6.4 ± 11.7	681	32.1 ± 23.6	22
22531	--	0	--	0	--	0
23658	5.7 ± 10.0	646	7.2 ± 12.4	645	29.4 ± 21.1	22
23661	5.8 ± 9.5	428	11.0 ± 19.3	336	18.6 ± 12.1	23
23657*	5.7 ± 8.3	1274	6.3 ± 9.5	1236	43.9 ± 30.16	29
22530*	9.8 ± 14.2	333	16.1 ± 20.0	371	15.9 ± 11.0	21
23659*	7.5 ± 11.3	431	11.0 ± 17.6	462	16.6 ± 9.9	26

*Turtles captured with longline fishing gear.

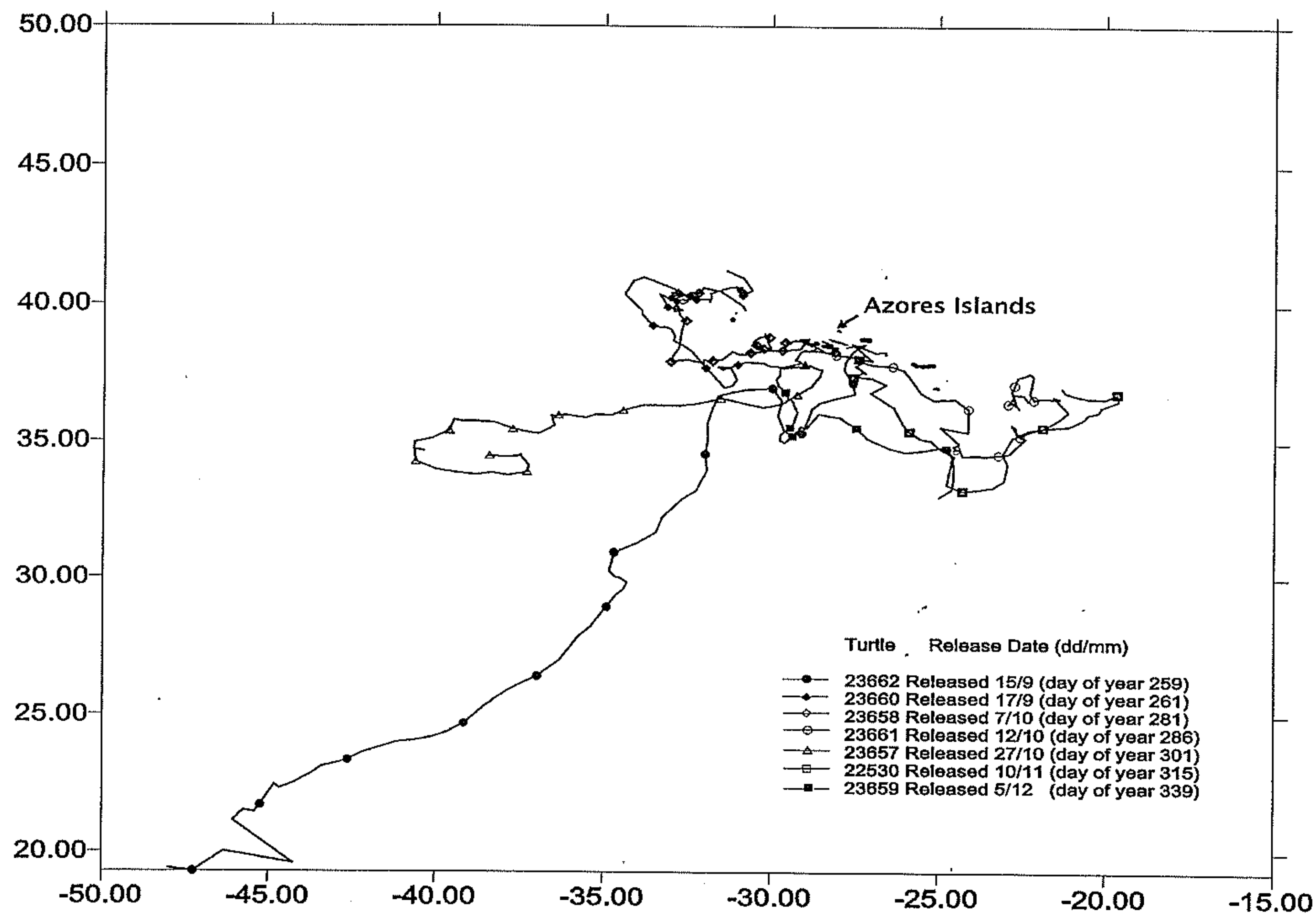

Figure 1(a). Movements of all turtles (except 22531) through 2-28-99.

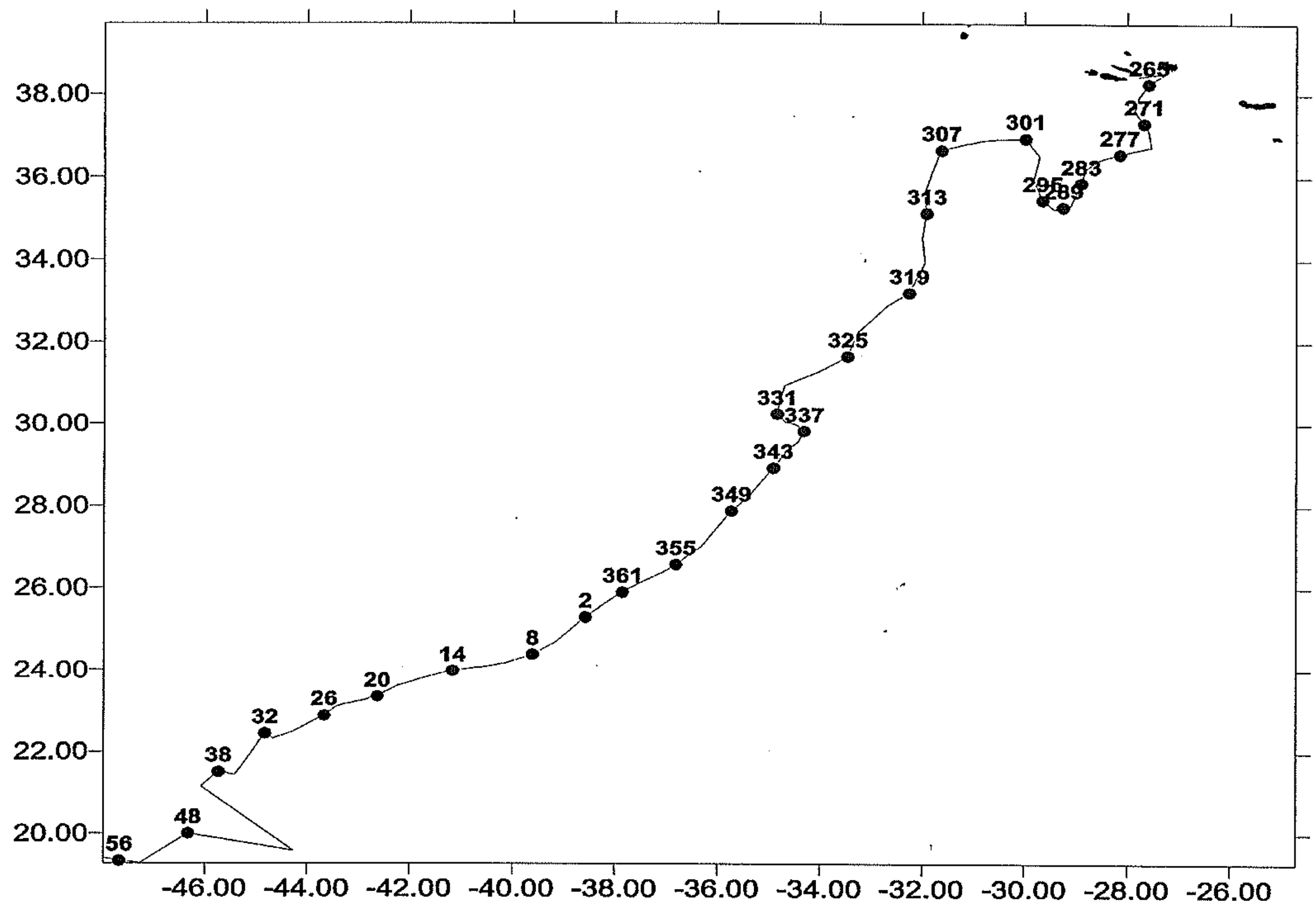

Figure 1(b). Movements of turtle 23662 from release on 9-15-98 (day of year 259) through 2-28-99 (day of year 59).

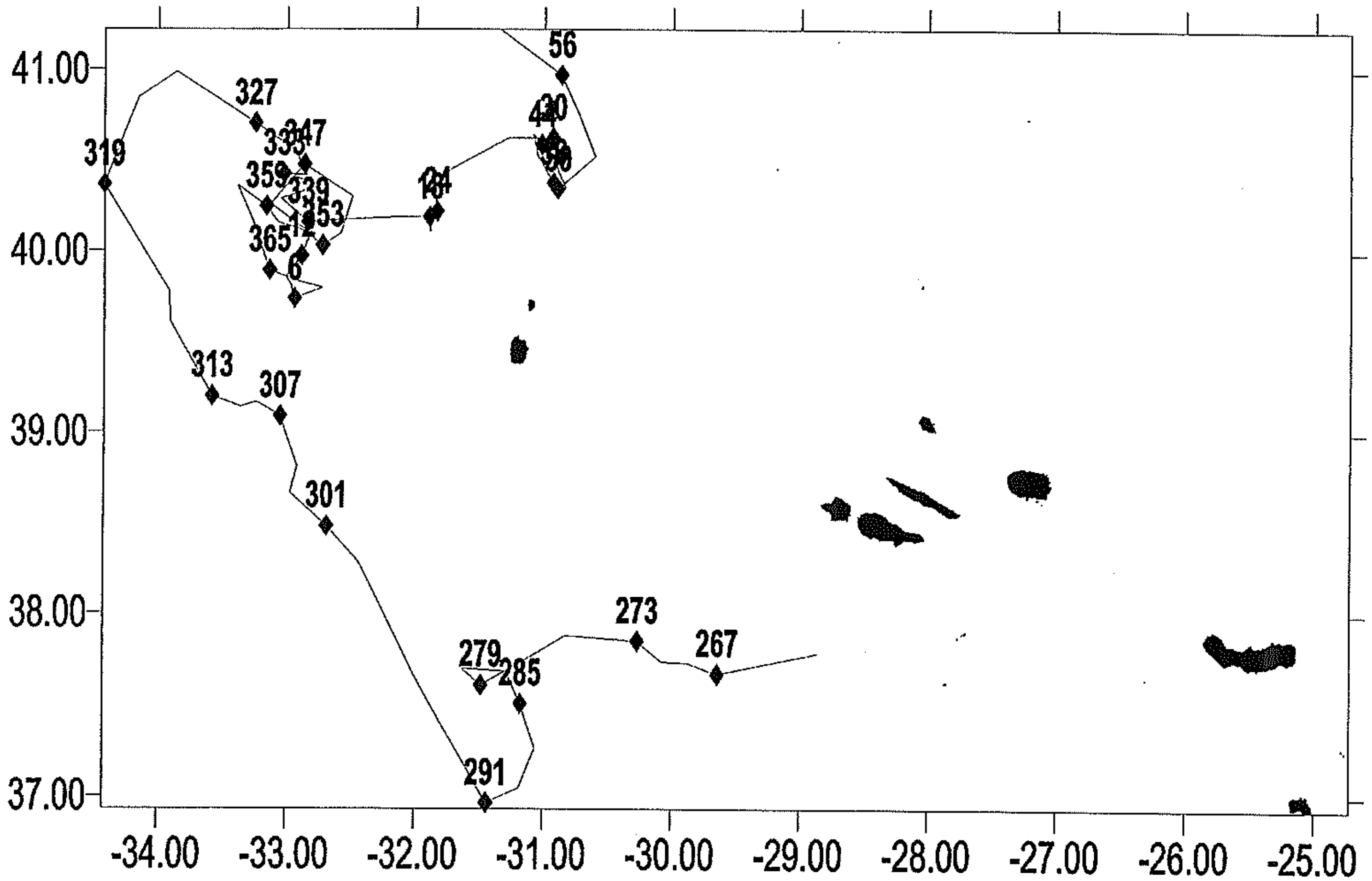

Figure 1(c). Movements of turtle 23660 from release on 9-17-98 (day of year 261) through 2-28-99 (day of year 59).

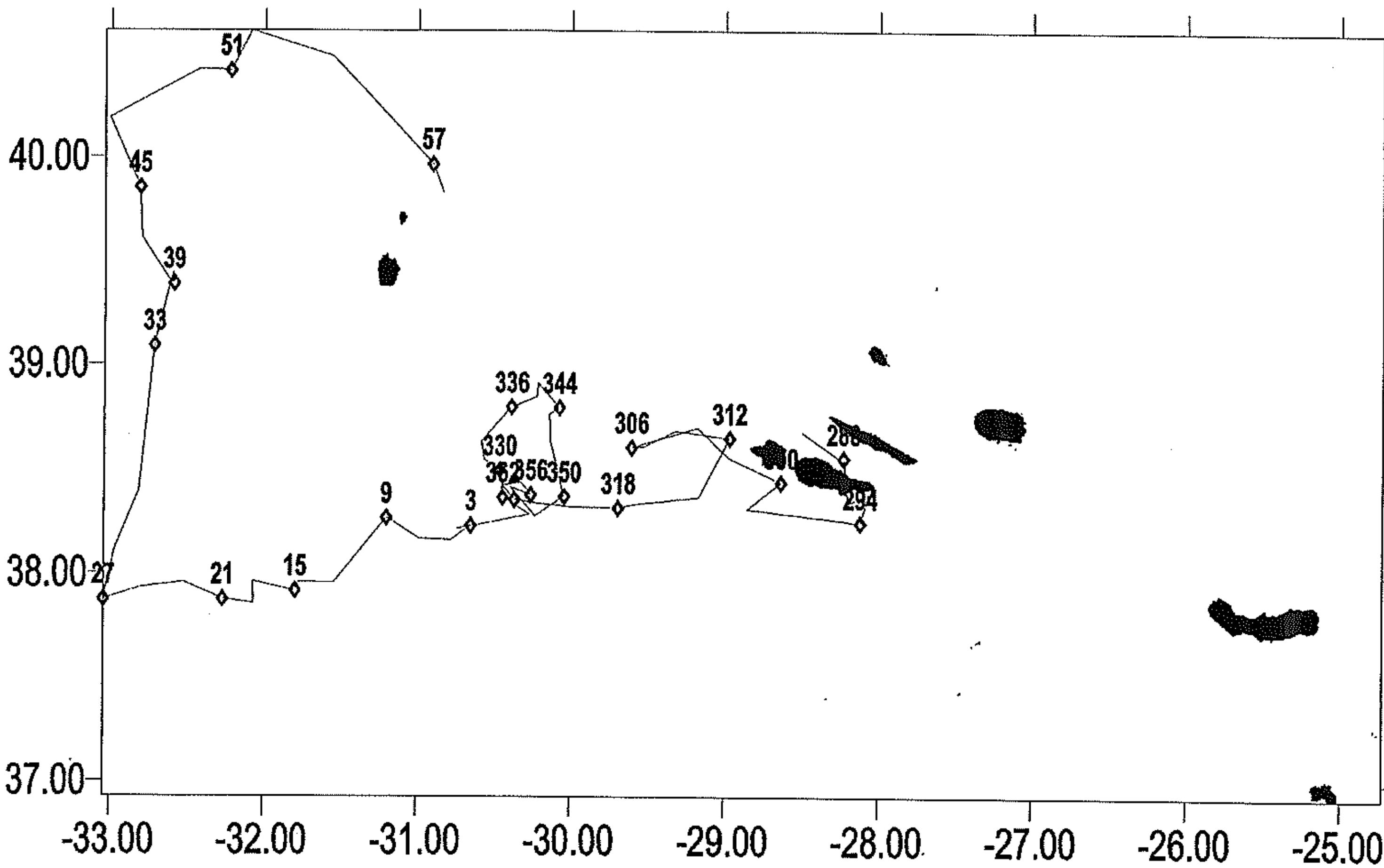

Figure 1(d). Movements of turtle 23658 from release on 10-7-98 (day of year 281) through 2-28-99 (day of year 59).

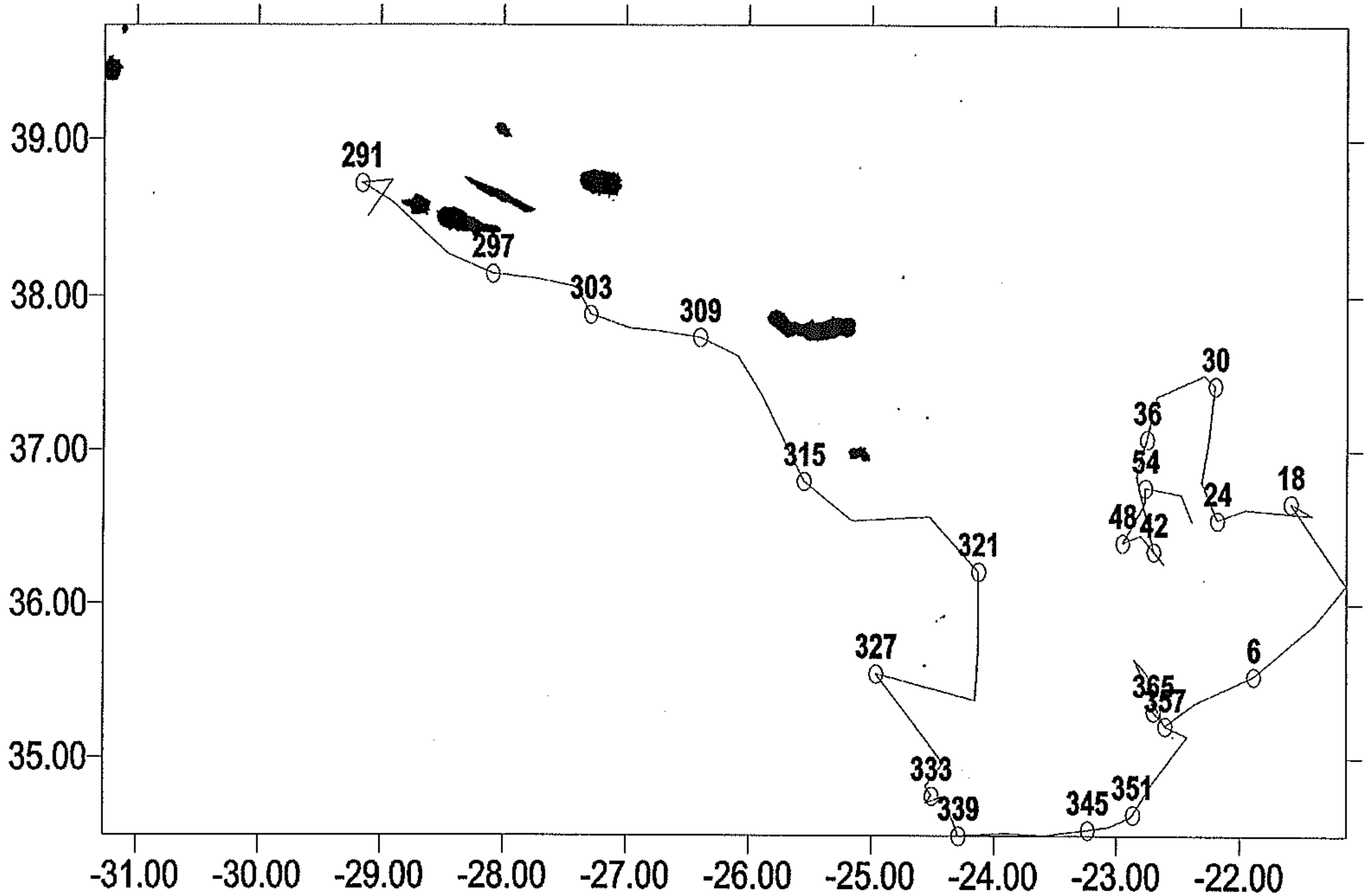

Figure 1(e). Movements of turtle 23661 from release on 10-12-98 (day of year 286) through 2-28-99 (day of year 59).

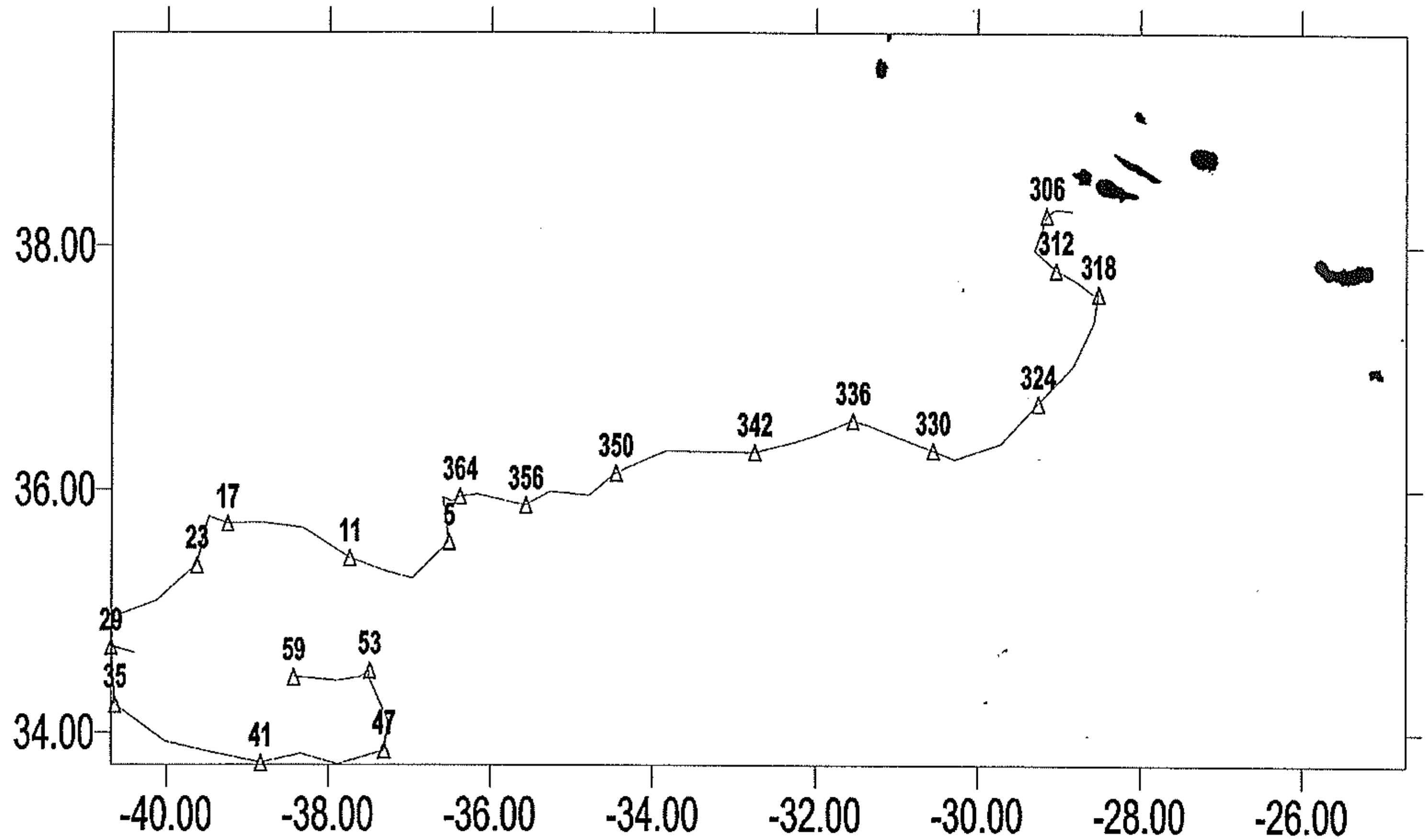

Figure 1(f). Movements of turtle 23657 from release on 10-28-98 (day of year 302) through 2-28-99 (day of year 59).

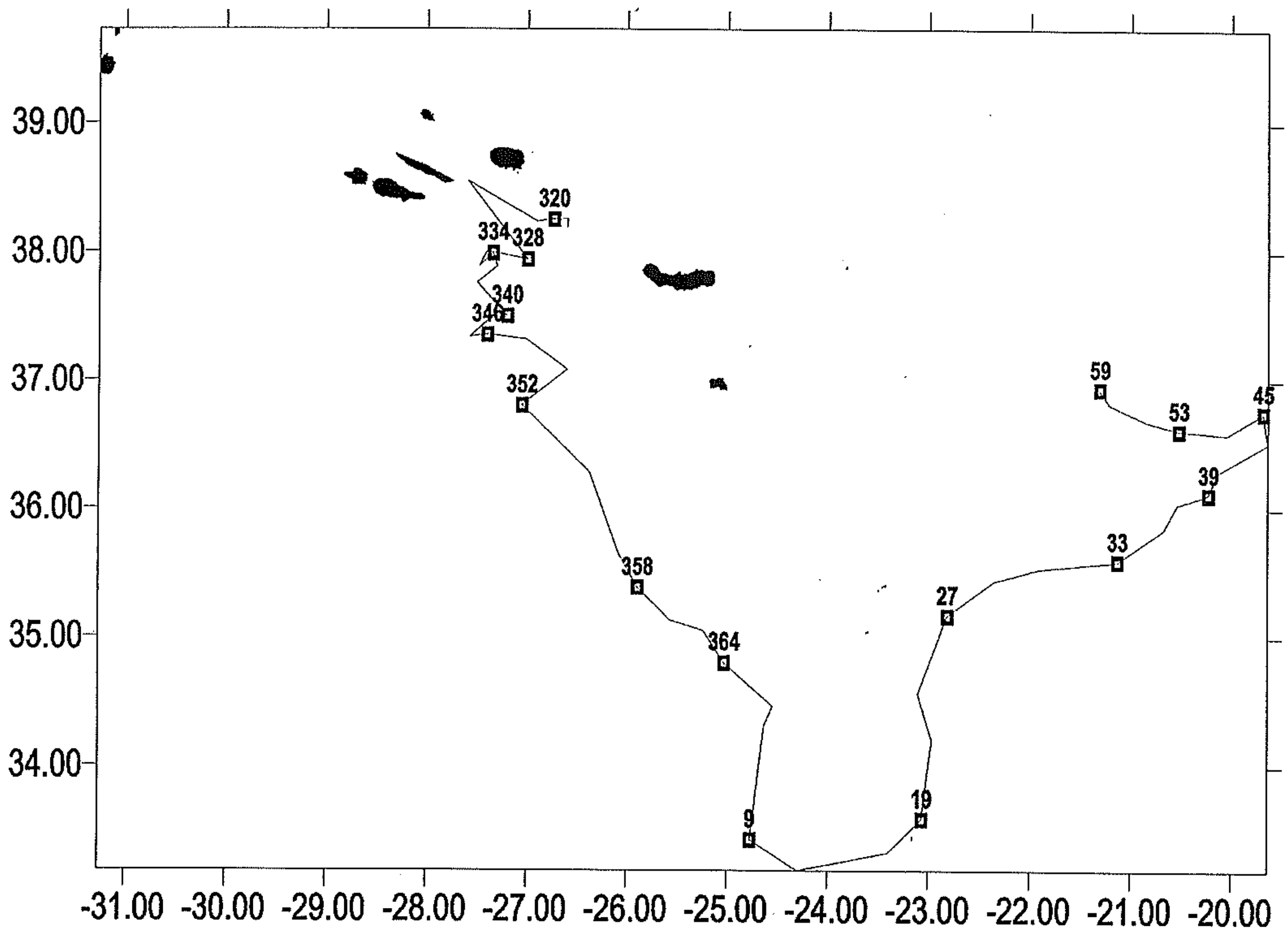

Figure 1(g). Movements of turtle 22530 from release on 11-11-98 (day of year 316) through 2-28-99 (day of year 59).

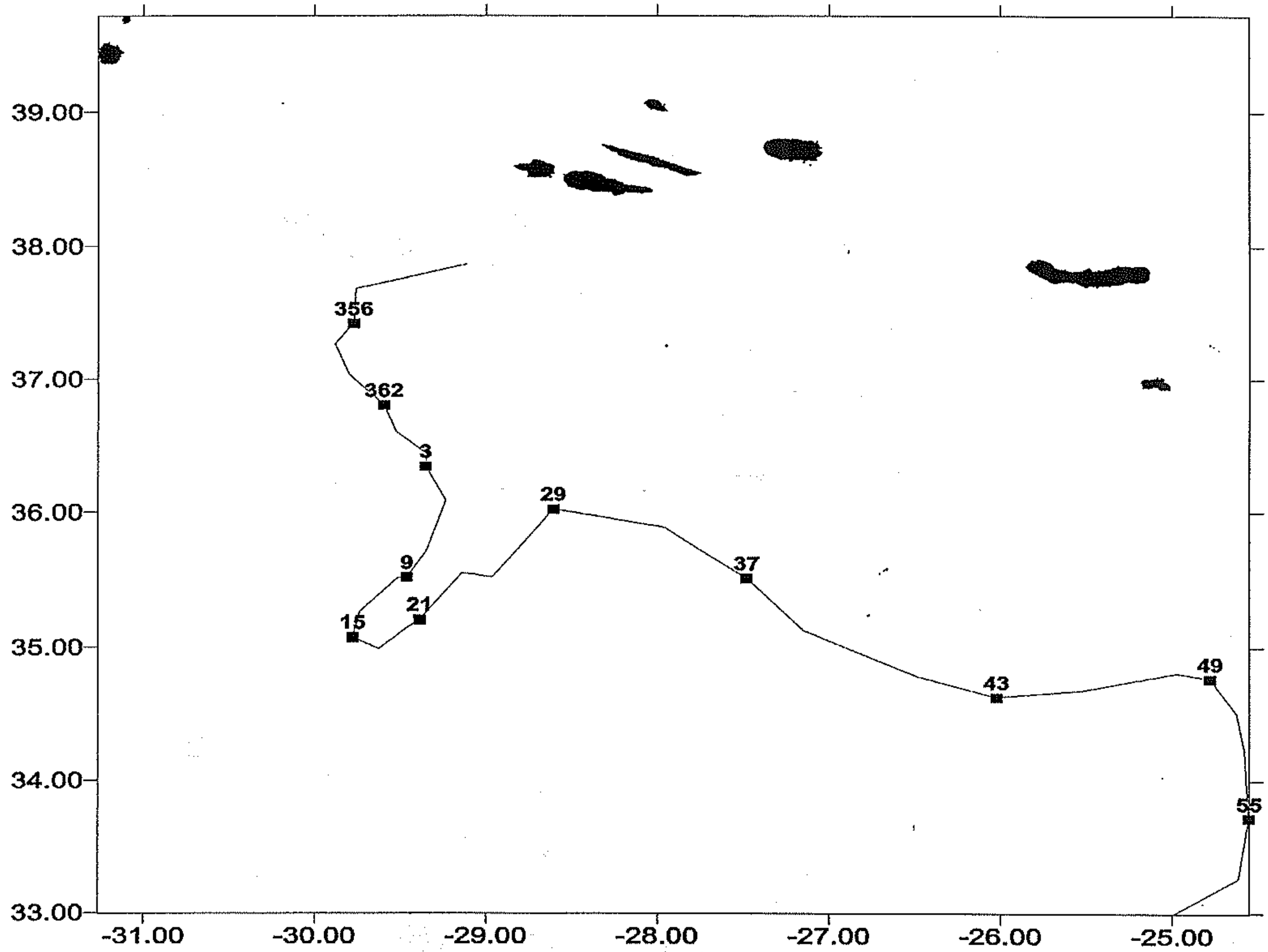

Figure 1(h). Movements of turtle 23659 from release on 12-5-98 (day of year 339) through 2-28-99 (day of year 59).

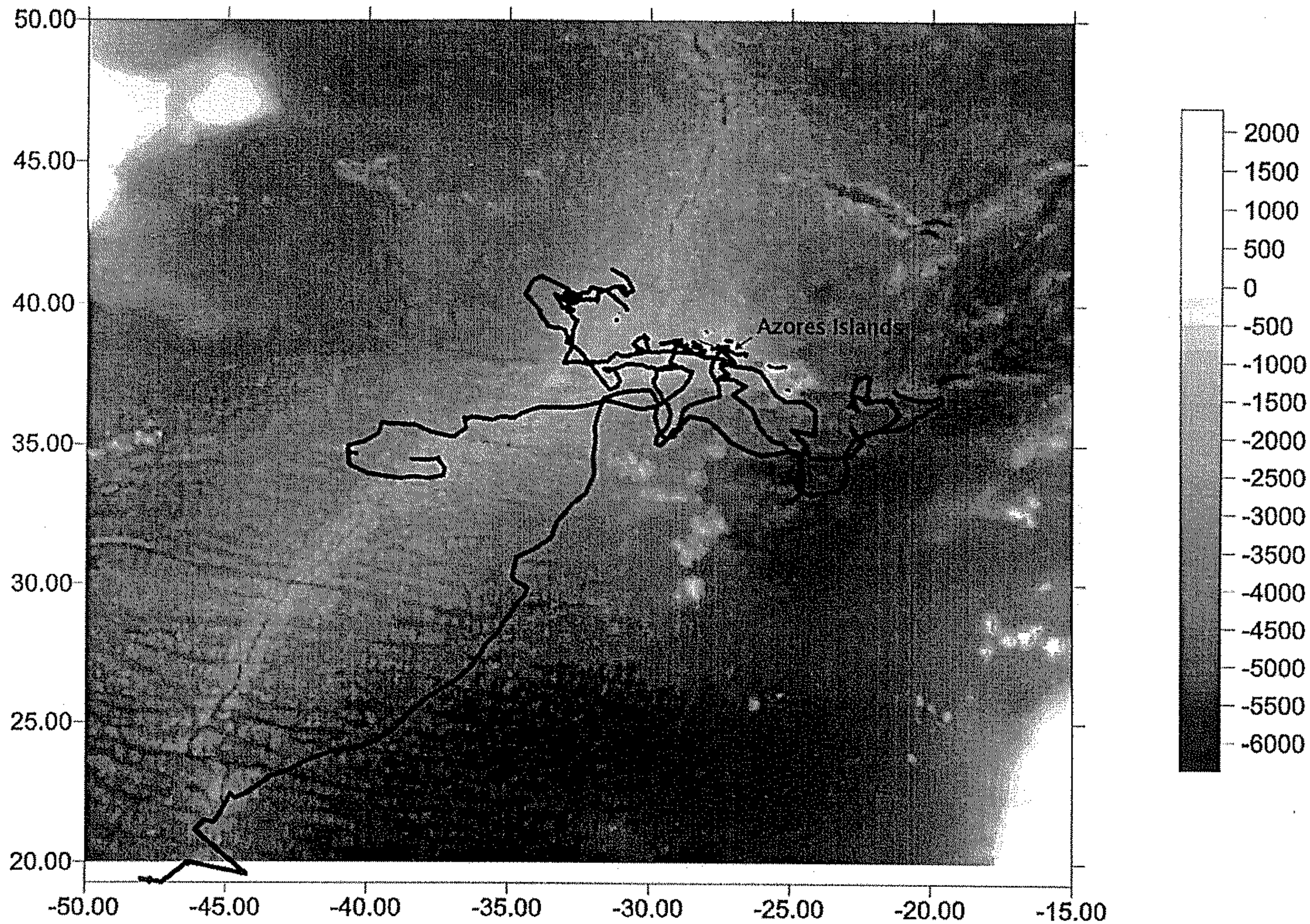

Figure 2. Movements of all turtles with respect to bathymetry. Depth scale is in meters.

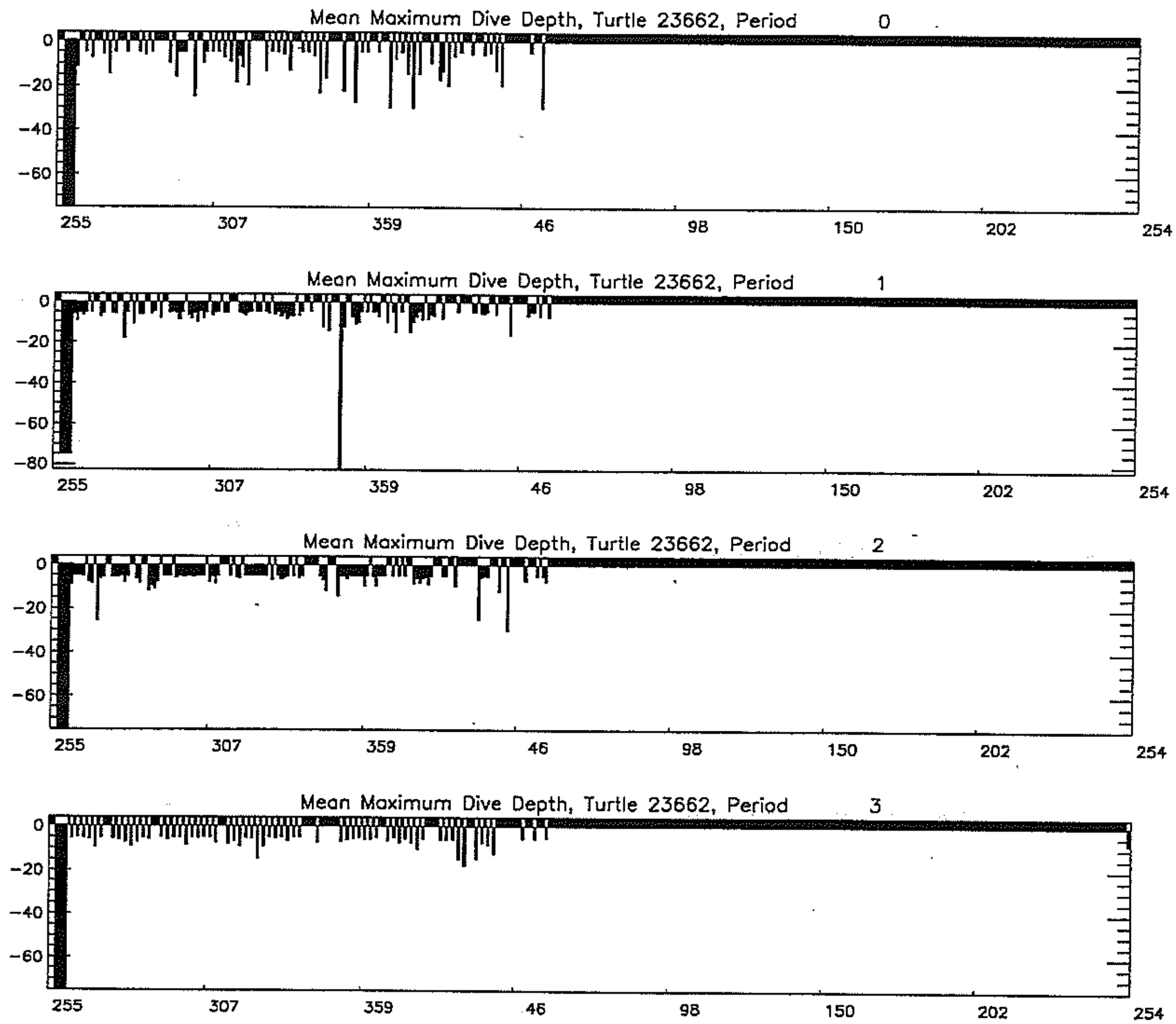

Figure 3(a). Mean-maximum-dive-depth (m) for turtle 23662 during each of four 6-hr histogram periods, plotted over time (day of year). Depth readings are shown as negative numbers. The thick black bar extending from the top to the bottom of each plot marks the release date. Positive depth values mark histogram periods for which no maximum depth histograms were received.

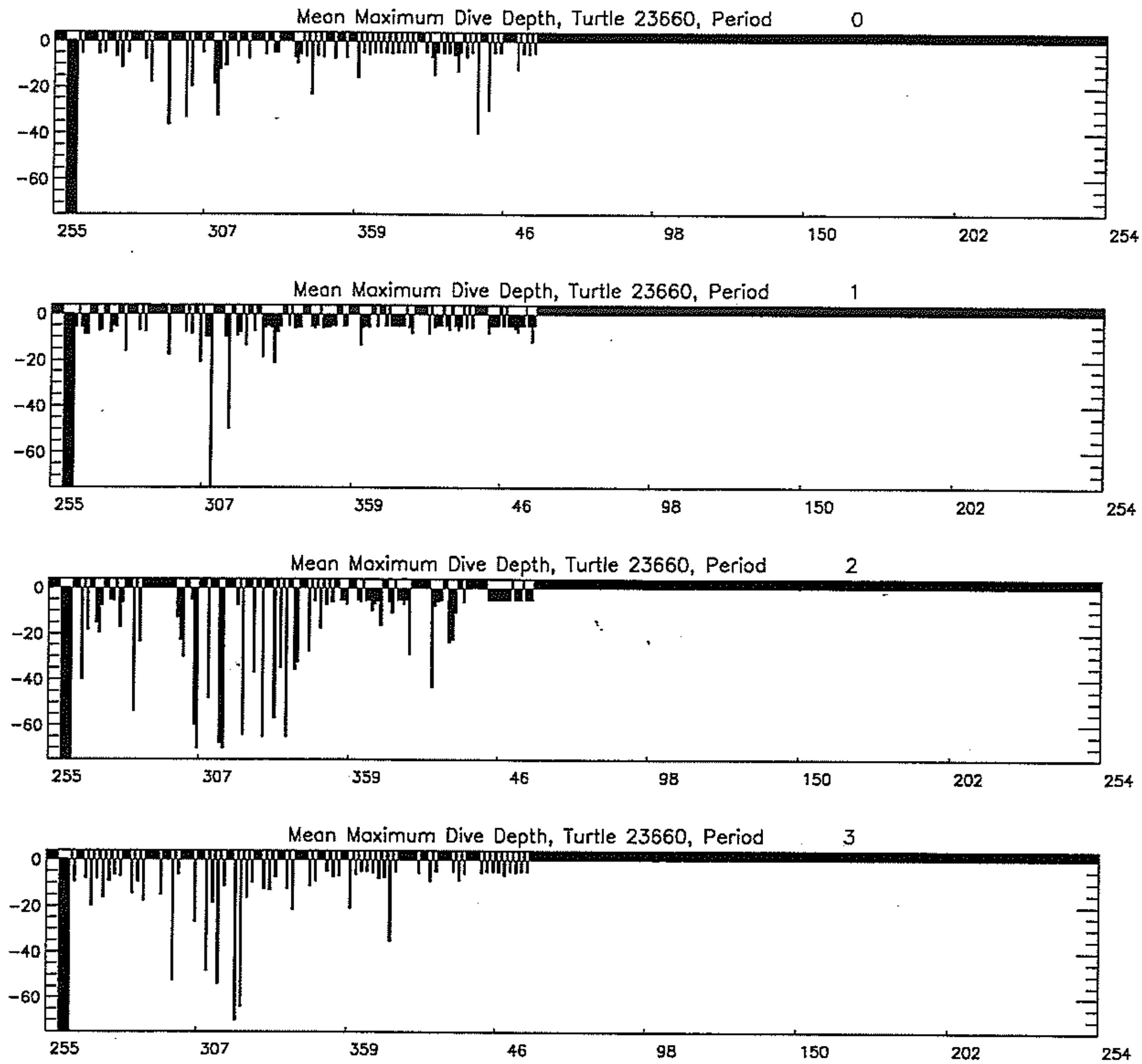

Figure 3(b). Mean-maximum-dive-depth (m) for turtle 23660 during each of four 6-hr histogram periods, plotted over time (day of year). Depth readings are shown as negative numbers. The thick black bar extending from the top to the bottom of each plot marks the release date. Positive depth values mark histogram periods for which no maximum depth histograms were received.

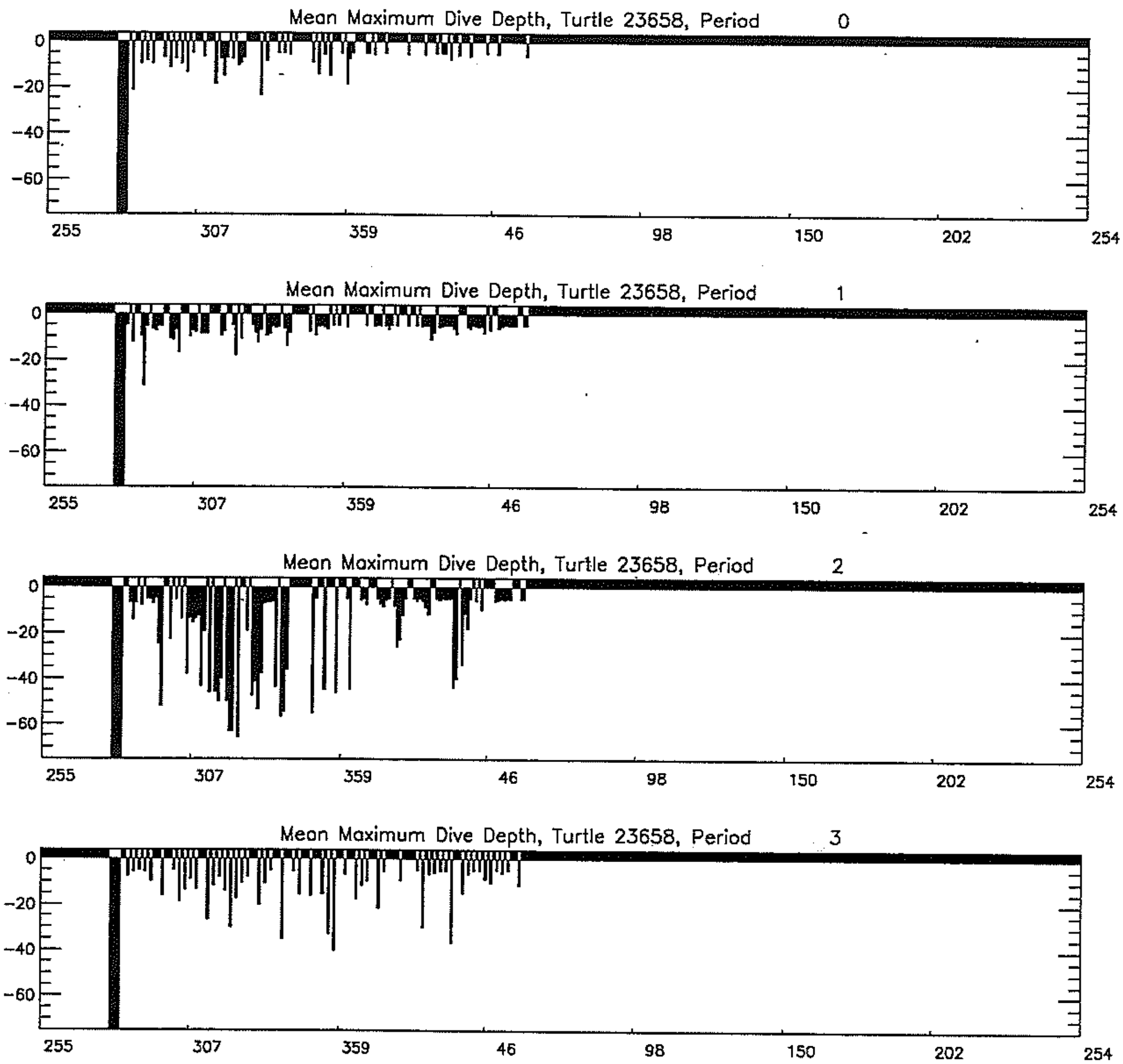

Figure 3(c). Mean-maximum-dive-depth (m) for turtle 23658 during each of four 6-hr histogram periods, plotted over time (day of year). Depth readings are shown as negative numbers. The thick black bar extending from the top to the bottom of each plot marks the release date. Positive depth values mark histogram periods for which no maximum depth histograms were received.